

# **SPECTRALLY ENHANCED LIGHTING**

**2013 DOE SSL R&D WORKSHOP**

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**Brian Liebel, PE**

**Rita Lee, AIA, LEED AP**

**The Lighting Partnership**

**[brian@thelightingpartnership.com](mailto:brian@thelightingpartnership.com)**

# Spectrally Enhanced Lighting

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# Known Effects of Spectrum on Vision

There are 2 regions of lighting in which spectrum has been demonstrated to affect vision:

- Interior Lighting: Spectrum affects visual acuity
  - IES TM-24-13, upcoming publication
- Mesopic Levels: IES TM-12-12



# Spectrally Enhanced Lighting

## ***US DEPARTMENT OF ENERGY TERM:***

- *A lighting design method for interior lighting applications by which lighting with relatively higher amounts of short wavelength energy (i.e. blue) can provide equal vision under reduced illumination, thereby saving energy.*
- **Formally called “Scotopically” Enhanced Lighting; that term should not be used.**
- *[http://www1.eere.energy.gov/buildings/spectrally\\_enhanced.html](http://www1.eere.energy.gov/buildings/spectrally_enhanced.html)*

# Basics: Light and Vision

The color of light has inherent qualities that have not been completely understood. Recent discoveries in vision science tells us that there's more to light than what we measure.



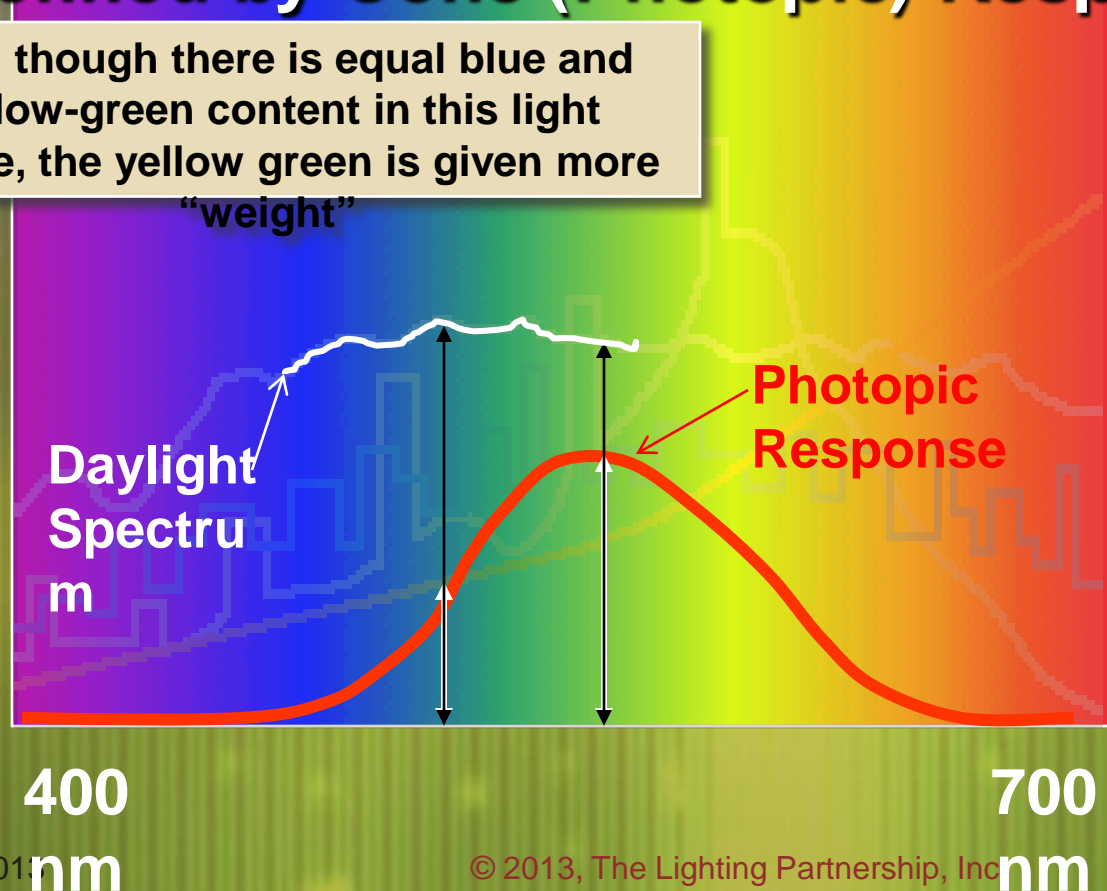
Using light sources with spectra more like daylight, but at the same light level:

- Makes the Eye's pupil smaller
- Improves Visual Acuity
- Affects Circadian Rhythm

# Basics: Light and Vision

- Light is the only SI unit based on Psychophysics:
- Defined by Cone (Photopic) Response (1924)

Even though there is equal blue and yellow-green content in this light source, the yellow green is given more "weight"



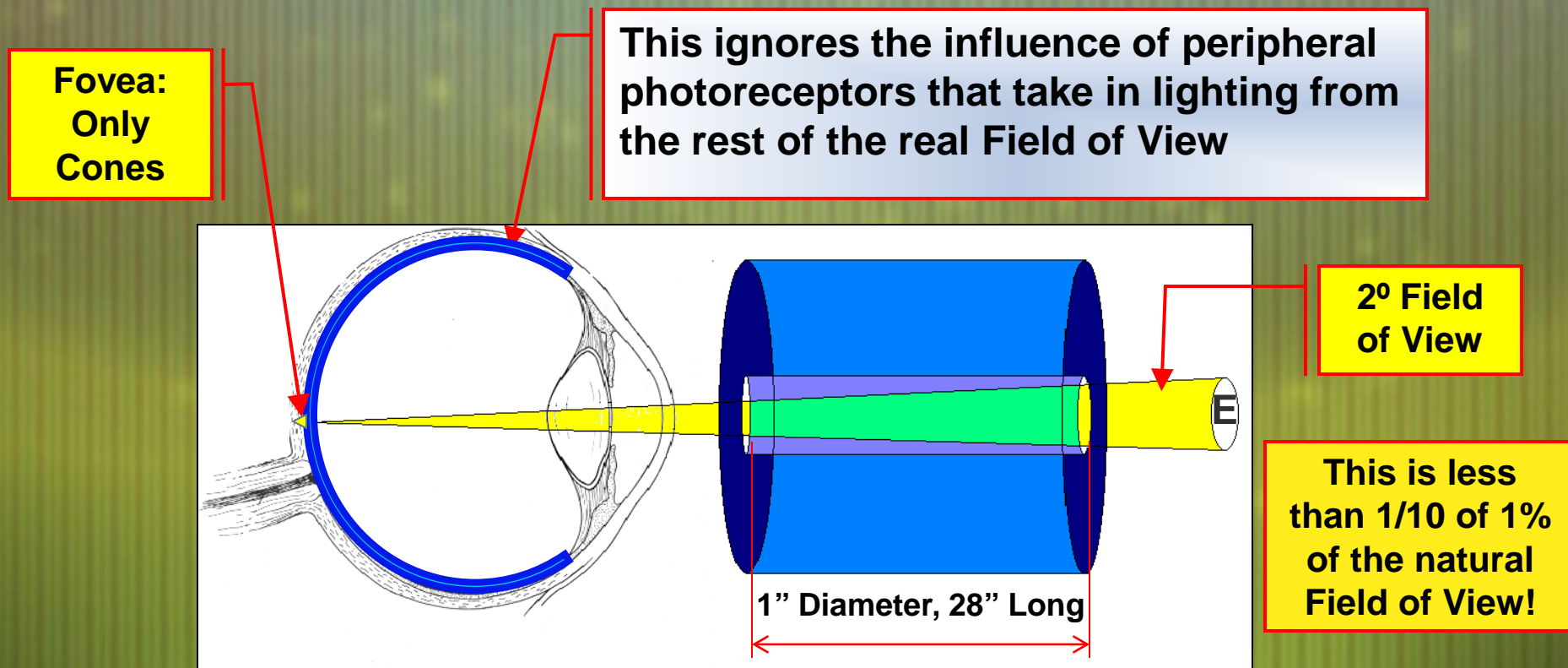
Lighting metrics rely solely on the photopic response.

Each wavelength intensity value from the light source is multiplied by the photopic response value at the same wavelength - then they are all added up to determine the lamp lumens.

# Basics: Light and Vision

## LIGHTING METRICS ARE BASED ON CONES ONLY:

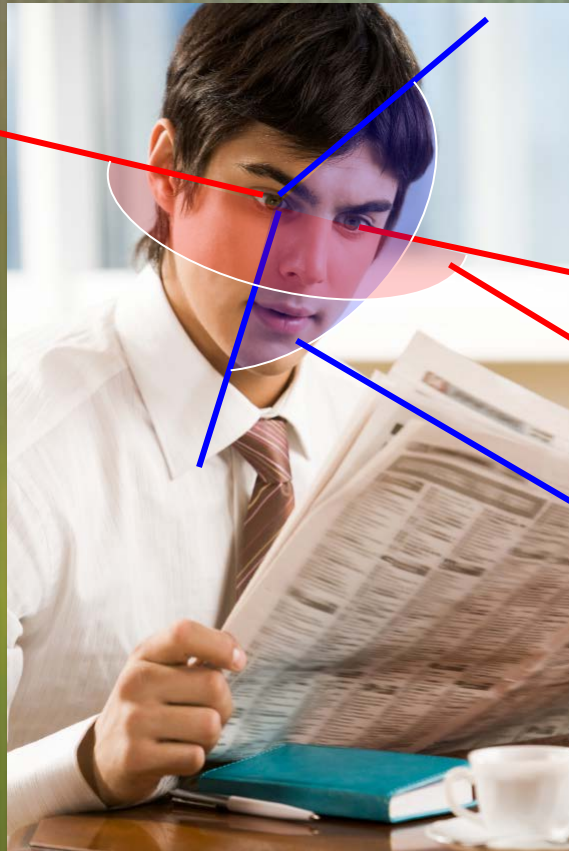
Determined under a very constrained field of view.





# Basics: Light and Vision

IN MOST INTERIOR LIGHTING APPLICATIONS,  
OUR EYES ARE EXPOSED TO A LARGE FIELD OF VIEW



Under a full field of view, the eyes have a different spectral response than what the photopic response predicts.

180°

Horizontal

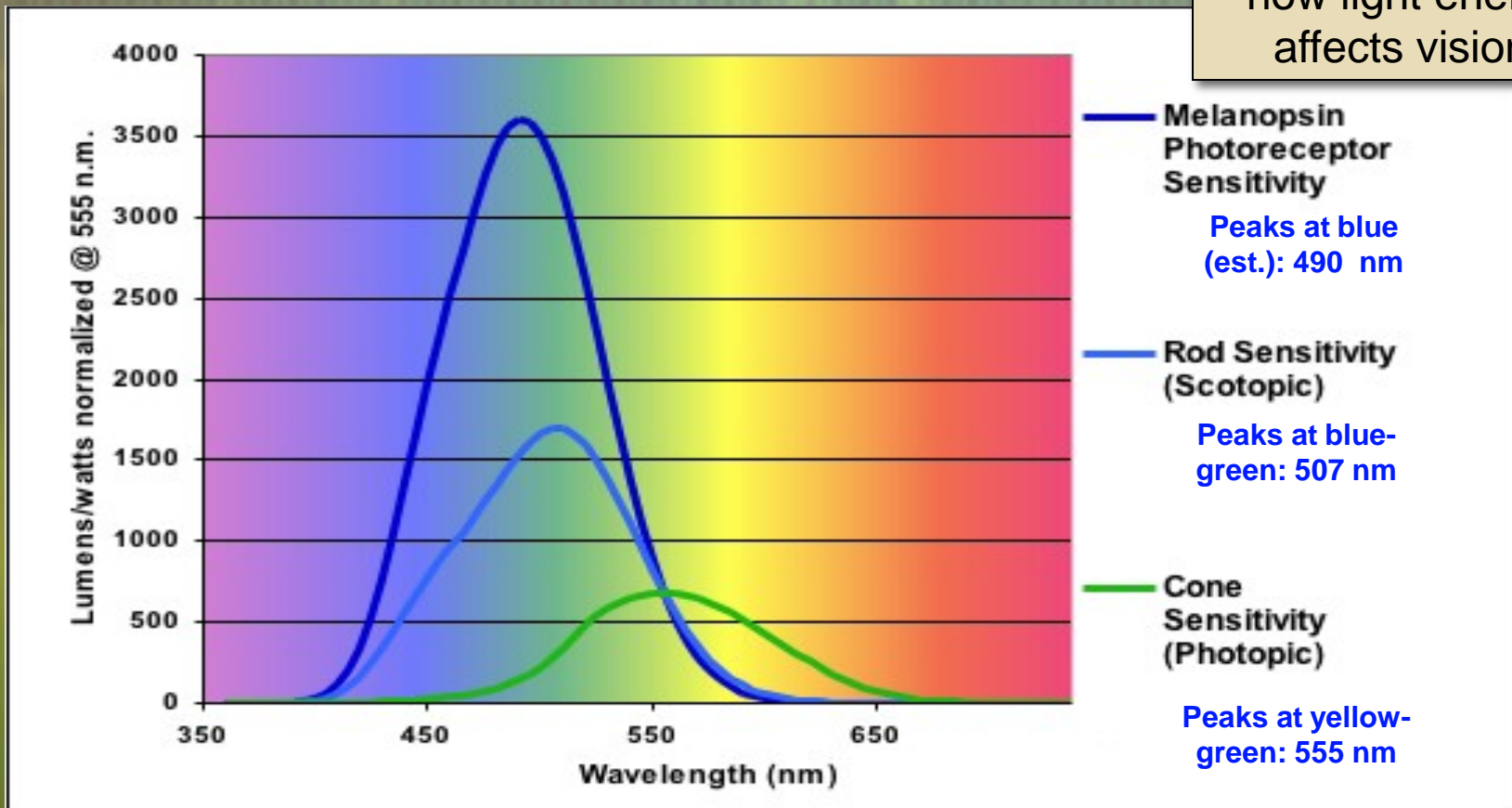
120° Vertical



# Basics: Light and Vision

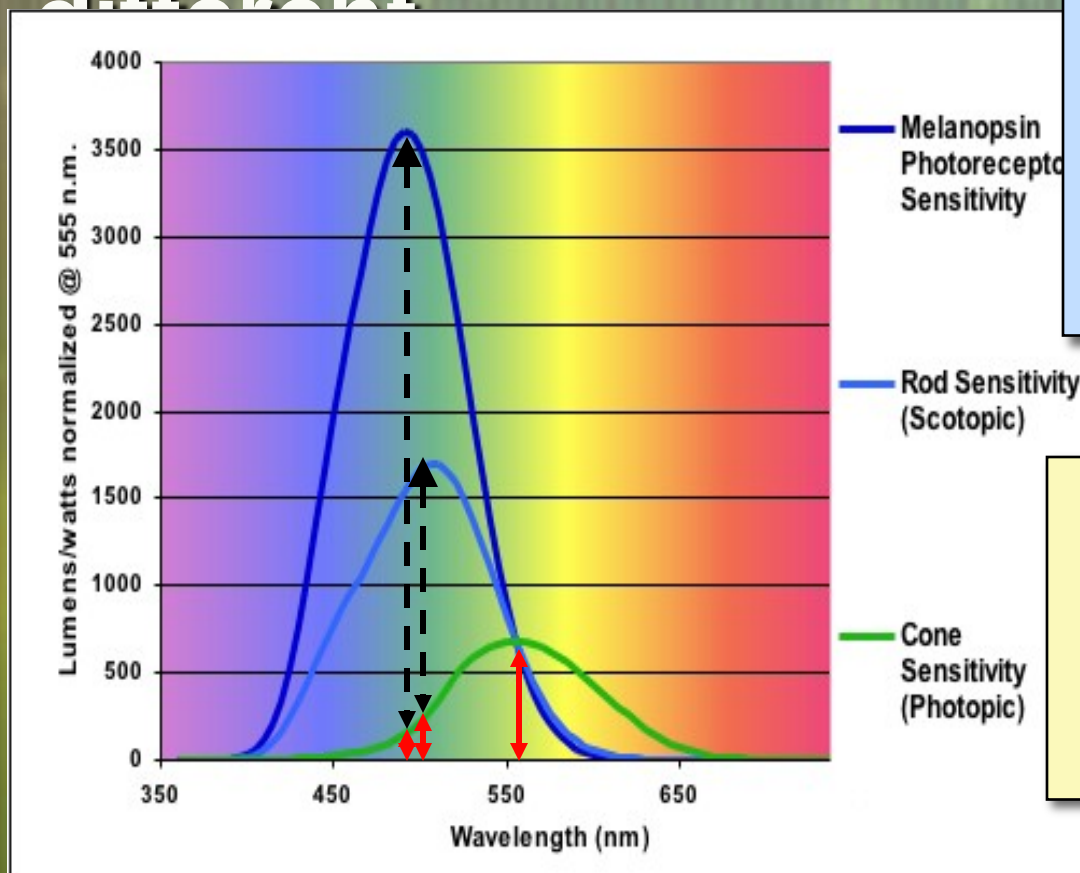
## 3 Photoreceptor Responses

There are 3 visual responses that can be used to evaluate how light energy affects vision.



# Basics: Light and Vision

## Peripheral photoreceptors are different



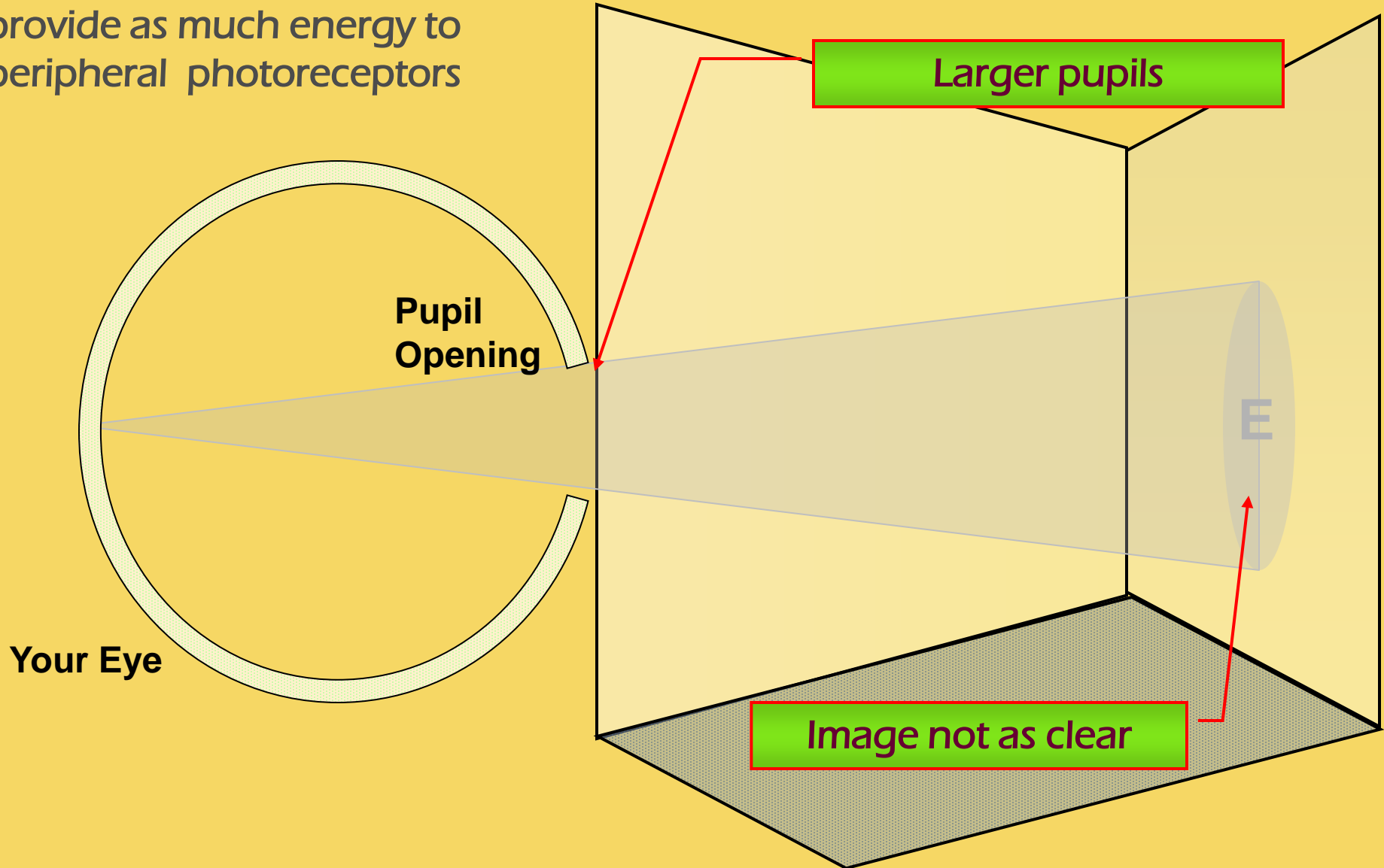
**Rod and ipRGC  
(Melanopsin)**

**Photoreceptor responses  
peak in blue: Photopic  
units ignore visual effects  
from these photoreceptors**

**Limiting our Lighting  
measurements to the  
Photopic Function misses  
the contribution of  
peripheral photoreceptors**

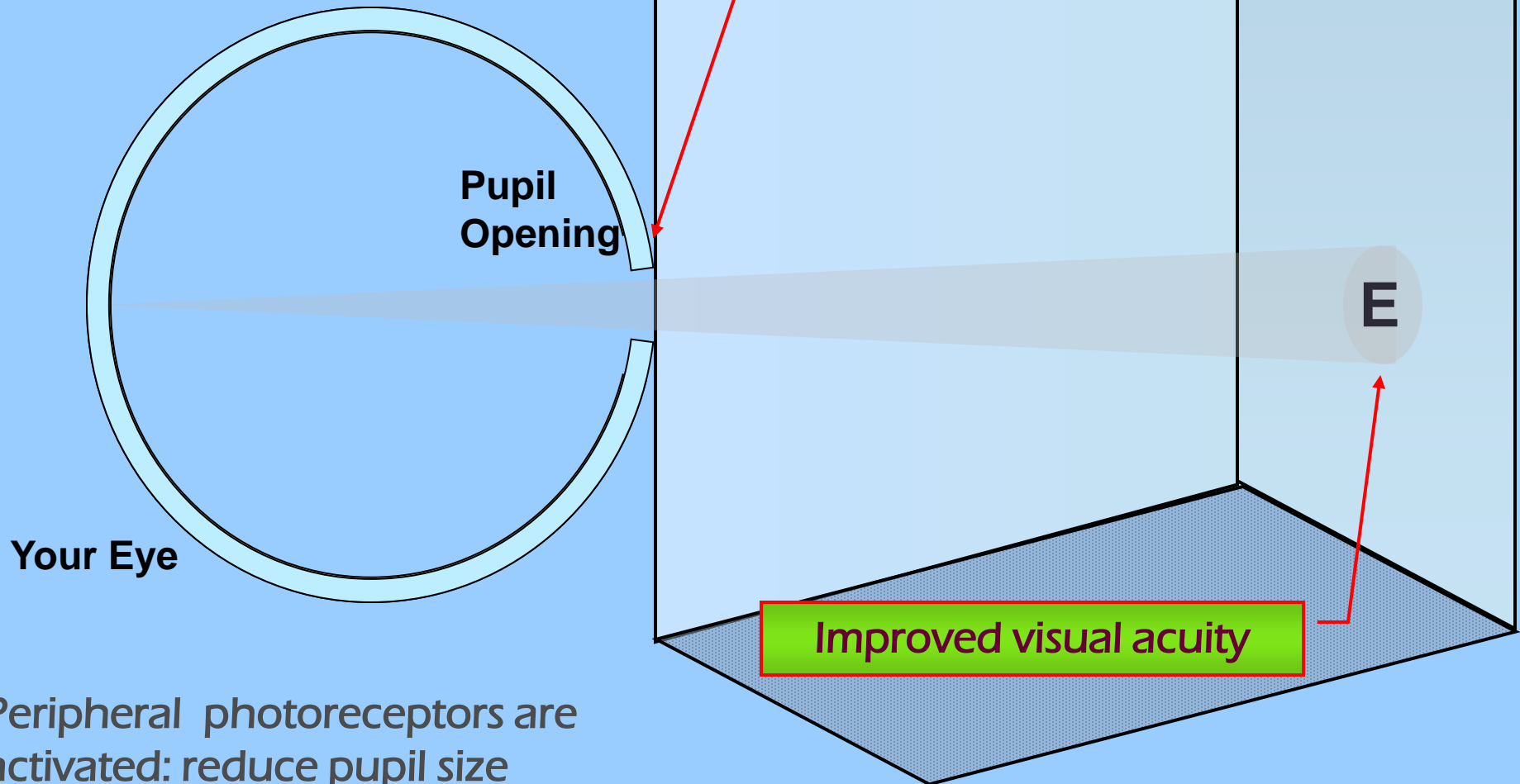
# Basics: Light and Vision

Warm Colored lighting does not provide as much energy to peripheral photoreceptors



# Basics: Light and Vision

If we keep the photopic light level the same, but change the spectrum of light to include more blue:



Peripheral photoreceptors are activated: reduce pupil size





Light Source



Shift Spectrum to Include More Blue



Peripheral Photoreceptors



Smaller Pupils



Increased Visual Acuity



Reduce Light Level —→ Save Energy

Equal Visual Acuity

# LIMITATIONS

## THIS METHOD IS LIMITED TO:

1. IES CATEGORIES P – Y, for tasks in which Visual Acuity is important;
2. TASK BACKGROUND LUMINANCE  $\geq 50$  cd/m<sup>2</sup>
3. GENERAL POPULATION, i.e. not a space where people have poor ocular health;
4. Tasks performed in FULL FIELD OF VIEW

# Pupil Size Variation Calculation

PUPIL SIZE CHANGE CAN BE  
CALCULATED USING BOTH LIGHT LEVEL  
AND SPECTRUM

P = Photopic  
Measuremen

$P(S/P)^{0.80}$

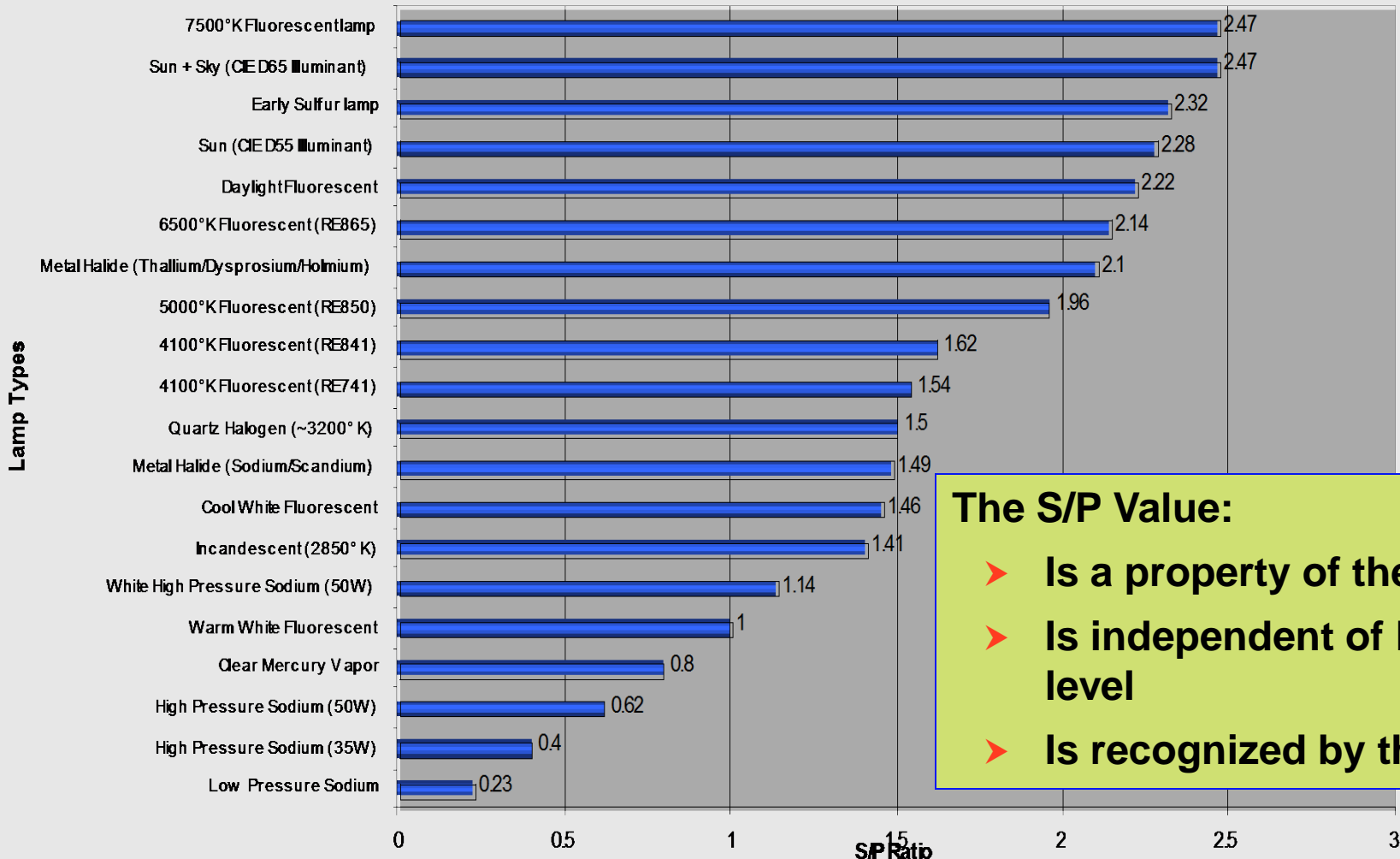
S/P Ratio  
(Scotopic/Photopic)

The S/P Ratio is a constant value for a light source whose  
spectral distribution does not vary with intensity

**(There is no ratified ipRGC spectral response function)**

# Examples of S/P Ratios

S/P Ratios of Various Lamps



## The S/P Value:

- Is a property of the lamp
- Is independent of light level
- Is recognized by the IES



# Equivalent Visual Efficiency (EVE) Equation

THE EVE CALCULATION ASSURES  
EQUIVALENT VISUAL ACUITY

$$\overbrace{P_1(S/P_1)}^{(\text{Light Level}) \times (\text{Spectrum})}^{0.8} = \overbrace{P_2(S/P_2)}^{(\text{Light Level}) \times (\text{Spectrum})}^{0.8}$$

$$P_2 = P_1 \{(S/P_1)/(S/P_2)\}^{0.8}$$

$$\overbrace{P_2}^{(\text{Light Level})} = \overbrace{P_1 \times \{(S/P_1)/(S/P_2)\}^{0.8}}^{(\text{Light Level}) \times (\text{Ratio of Spectrums})}$$

**APPLIES TO IES CATEGORIES P-Y  
ONLY!**

# Equivalent Visual Efficiency (EVE) Equation

**Example:**

**Base Case is 400 lux, S/P=1.4**

**Proposed new illuminant S/P=2.0**

$$P_2 = 400 \{1.4/2.0\}^{0.8}$$

$$P_2 = 300 \text{ lux}$$

***25% illuminance reduction, same visual  
acuity***

# Applications – Building Retrofits

## Comparison



Before



After

# Occupant Reaction to High CCT Lighting

## Studies Demonstrate Acceptance up to 6500K

- **2004 DOE/PG&E/UCOP Study: Occupant acceptance of 850, under lower light level than 835.**
- **2006 DOE Field Study: 3 Buildings completely retrofit with 850 lamps and standard ballasts**
- **2006: LRC STUDY: 3500K @ 500 lx compared to 6500K @ 340 lx - No Difference in Occupant Ranking of 10 subjective feelings**



# Designer Reaction to High CCT Lighting

- Designers have been trained to believe that people prefer warm CCTs: “Kruithof Effect” (1941)
- More recent research suggests otherwise; provided that occupants are fully adapted to the lighting, the CCT of the lamps has little effect on people’s impressions of the lighting in the room.
- Designers that have used Spectrally Enhanced Lighting tend to stick with it.

# Businesses That Have Standardized

## Companies/Institutions using 850 lamps:

- **Pacific Gas & Electric Company**
  - PG&E now calls SEL one of the top 5 strategies for lighting energy efficiency.
- **San Diego Unified School District**
- **Cities of San Diego and Oakland**
- **Counties of Napa and San Mateo**
- **State of Wisconsin**

**All these have adopted 5000K lighting as their standard for retrofits and new construction.**

# Status in IES

- **A Technical Memorandum (TM-24-13) has been approved by the IES Board of Directors**
- **TM-24-13 Allows the EVE Method for use under certain restrictions; it is optional, not mandatory**
- **TM-24-13 Includes a Position Statement; it should not be used by energy regulators as a justification for lowering Lighting Power Densities (LPDs) in energy Standards or legislation**

# Optimized Light Source

- An ideal light source will have:
  - High S/P ratio for visual clarity;
  - High color rendering properties to render objects and spaces realistically
  - High efficacy, to minimize energy consumption.
- The CCT of the lighting will be dependent on the designer, the owner/occupant, the compatibility with the finishes, and compatibility with other light sources in the space, etc.



# CONTACT INFO

**Brian Liebel, PE**

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**brian@TheLightingPartnership.com**

*DOE Website:*

*[http://www1.eere.energy.gov/buildings/spectrally\\_enhanced.html](http://www1.eere.energy.gov/buildings/spectrally_enhanced.html)*